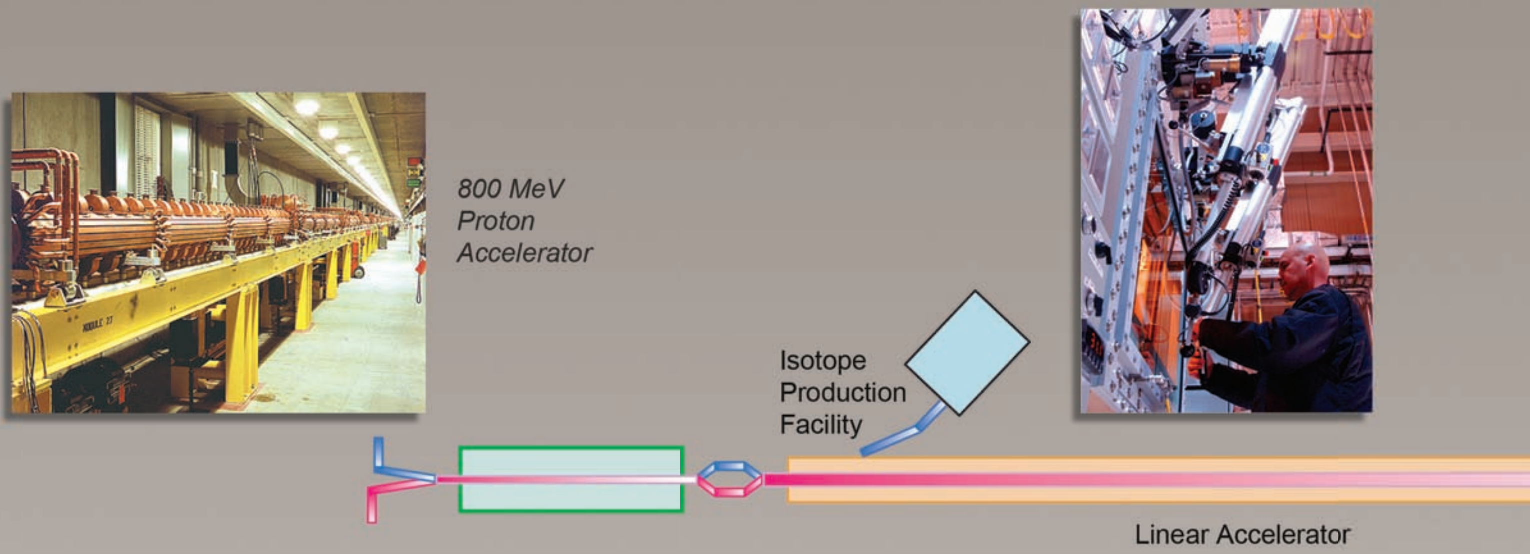

LANSCE

A Key Facility for National Science and Defense

Kurt F. Schoenberg and Paul W. Lisowski

For over thirty years, the Los Alamos Neutron Science Center (LANSCE) has been a premier accelerator-based user facility for national security and fundamental science. LANSCE has remained at the forefront of research because of its strength in technological innovation and its capacity to tailor its very intense proton beam and beam delivery modes to changing scientific and programmatic needs. Today, five state-of-the-art facilities operate simultaneously, contributing to the nuclear weapons program (including actinide and high explosives science), nuclear medicine, materials science and nanotechnology, biomedical research, electronics testing, fundamental physics, and many other areas. During eight months of the year, while the accelerator is operational, scientists from around the world work at LANSCE to execute an extraordinarily broad program of defense and civilian research. Over the 2004 operating period, there were more than 1100 user visits at LANSCE, and over 350 experiments were performed. In 2005, the number of user visits increased to over 1200. Because of its large user program, LANSCE is one of the Laboratory's most important "windows" into the academic community and a source for many of our brightest early-career scientists. LANSCE can claim no less than 1200 recruits to the Los Alamos National Laboratory's technical staff during the last 30 years, and it remains a magnet for the best and the brightest.

Plans to refurbish the facility and extend its role are in the works. The LANSCE refurbishment project is designed to sustain reliable facility operations well into the next decade for defense research and applications. A Materials Test Station delivering a very intense fast neutron flux has been designed for exploring advanced nuclear-energy options. A newly commissioned ultracold-neutron-source user facility will make high-precision tests of the standard model of elementary particle physics. Upgrades at the proton radiography facility will enable high-resolution high-speed imaging of hydrodynamic instabilities and detonation physics of importance to stockpile stewardship. Enhancements to the existing Lujan Neutron Scattering Center will ensure its preeminence in cold, long-wavelength neutron scattering for the foreseeable future. The development of a long-pulse neutron source prototype will explore techniques for achieving a hundredfold increase in neutron flux for designing the materials and pharmaceuticals of the future. These and other plans promise that LANSCE will support the nation's nuclear deterrent, energy security, health and welfare, and leadership in science for many decades to come.


Proton Radiography
Nuclear Energy
Materials Test Station
Proton
Radiography
Ultracold
Neutron Source
Fundamental Physics
Drug Design
NATIONAL SECURITY
Proton
Storage
Ring
Lujan
Center
Nuclear Data
Weapons
Neutron
Research
Facility
ICE House
Aviation Safety
Nanomaterials

Figure 1. Aerial View of the LANSCE Facility

The heart of the Los Alamos Neutron Science Center (LANSCE) is the high-intensity linear proton accelerator (linac), stretching eastward from the Laboratory along a narrow mesa top (Figure 1). Conceived in the 1960s by Louis Rosen, a veteran of both the Manhattan Project and the thermonuclear era, it was to be a world-class facility designed to extend the reach of the Los Alamos community into the international scientific arena. To complement the studies into the nature of elementary particles conducted at other institutions, the Los Alamos Meson Physics Facility (LAMPF) would produce the highest-intensity proton beam in the world to explore the fundamental forces of nature at medium energies. These are the energies at which pi mesons are produced, and their role in holding together the protons and neutrons of ordinary nuclei could be studied.

LAMPF was an exciting project based on an innovative accelerator design, but a first-class meson physics facility was only one part of the total vision. Just as protons from the linac, traveling at 84 percent of the speed of light, would produce copious numbers of pi mesons when they crashed into a light-element target, the same protons, striking the neutron-rich nuclei of a heavy-metal target, would release copious numbers of neutrons through a process called spallation. Those neutrons would be perfect for studying the nuclear and materials physics that determines the performance of a nuclear weapon, as well as neutron radiation effects on reactor and weapons materials, and a neutron physics facility would be especially needed if there ever were a moratorium or ban on nuclear weapons testing. The argument was presented, and the U.S. Congress saw its validity. Even before the 800-million-electron-volt (MeV) linac was complete, Congress had agreed to support a Weapons Neutron Research (WNR) Facility to complement the activities of LAMPF, thereby making LAMPF a world-class research facility for both science and national security.

Today, neutrons and protons have eclipsed mesons as the primary research tools provided at the facility; the name of the facility has been changed to the Los Alamos Neutron Science Center, or LANSCE; and the research emphasis has shifted from medium-energy nuclear physics to material and nuclear science in sup-

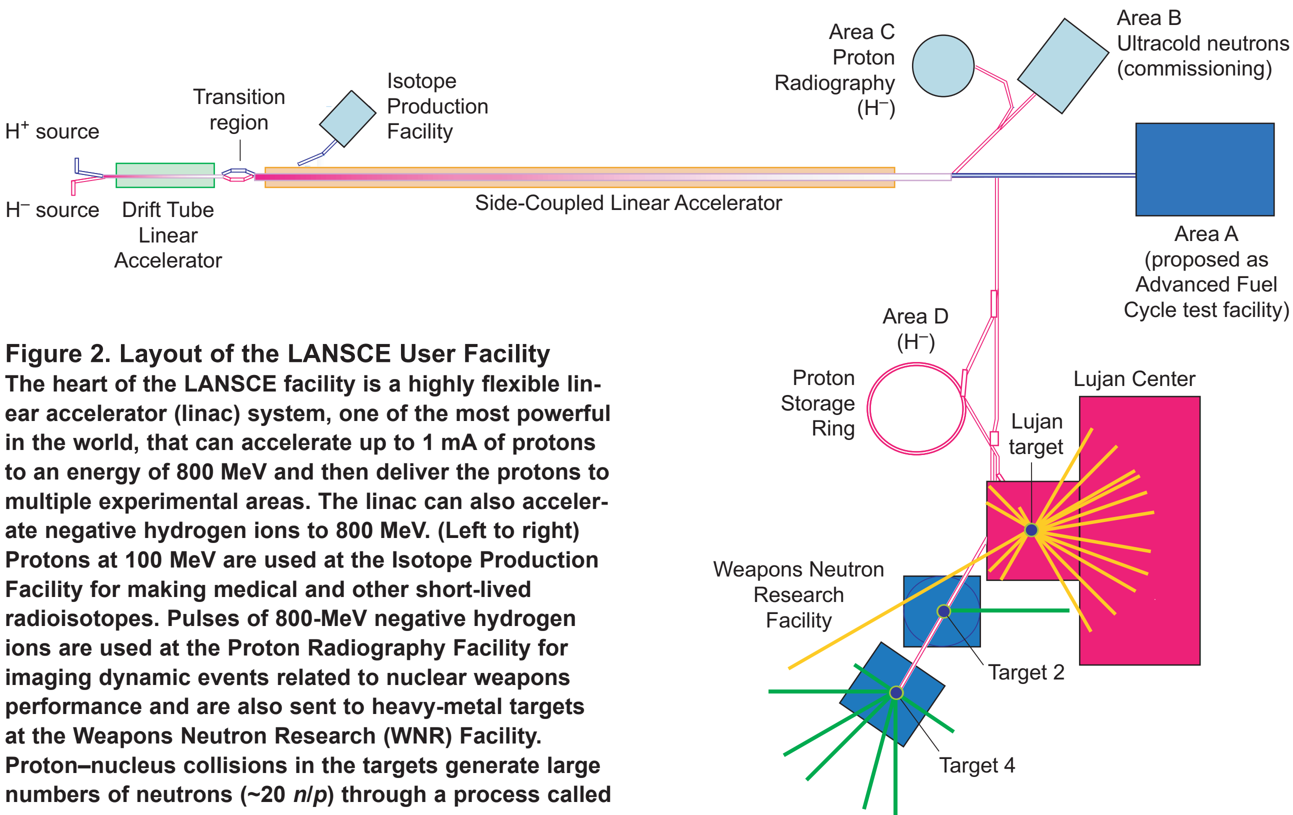

Figure 2. Layout of the LANSCE User Facility
The heart of the LANSCE facility is a highly flexible linear accelerator (linac) system, one of the most powerful in the world, that can accelerate up to 1 mA of protons to an energy of 800 MeV and then deliver the protons to multiple experimental areas. The linac can also accelerate negative hydrogen ions to 800 MeV. (Left to right) Protons at 100 MeV are used at the Isotope Production Facility for making medical and other short-lived radioisotopes. Pulses of 800-MeV negative hydrogen ions are used at the Proton Radiography Facility for imaging dynamic events related to nuclear weapons performance and are also sent to heavy-metal targets at the Weapons Neutron Research (WNR) Facility. Proton–nucleus collisions in the targets generate large numbers of neutrons (~20 *n*/*p*) through a process called nuclear spallation. The neutron pulses, in turn, are used for materials irradiation and fundamental and applied nuclear physics research. The negative hydrogen ions are also injected into a 30-m-diameter Proton Storage Ring (PSR). The PSR converts a 625-μs pulse of negative hydrogen ions into a 125-ns intense burst of protons. Those intense proton bursts produce, through nuclear spallation, short bursts of neutrons for neutron scattering studies of material properties at the Lujan Center and for nuclear physics research at the WNR. In addition, a newly commissioned ultracold-neutron research facility is beginning the exploration of fundamental nuclear physics with experiments designed to test the standard model of elementary particles.

port of Laboratory missions. The Lujan Neutron Scattering Center (Lujan Center) has become a major international user facility for studying the structure and dynamics of advanced materials and biological macromolecules. Semiconductor industries come to use the intense high-energy neutron flux at the WNR's Irradiation of Chips and Electronics (ICE) House to test the vulnerability of their modern circuit designs to disturbances caused by atmospheric neutrons; and biomedical companies collaborate with staff at the new Isotope Production Facility to get the latest radioisotopes for nuclear medicine and research applications. (Figures 1 and 2 show the layout of the facility.)

The national security efforts at LANSCE have increased markedly over the past decade. Los Alamos scientists have developed an unmatched suite of precision instruments that exploit the intense, high-energy neutron source at the WNR, the highest-intensity source in the world, to supply essential nuclear data for predicting the performance of our nuclear deterrent from first principles and benchmarking the results against past tests. Proton radiography is a new technique invented at Los Alamos, in collaboration with Lawrence Livermore National Laboratory and other national laboratories, for imaging dynamic events with protons rather than x-rays. It is being used to investigate the high-explosive detonation physics and hydrodynamic instabilities important to the weapons program. Instruments at the Lujan Center have been tailored to study material properties of high explosives, plutonium, uranium alloys, and other weapons materials under varying conditions of temperature and pressure. And the new Isotope Production Facility is producing the short-lived and rare isotopes needed for nuclear data experiments of interest to the nuclear weapons program. As Louis Rosen likes to say, "Technology is the child of science," and that maxim could not be truer than at LANSCE.

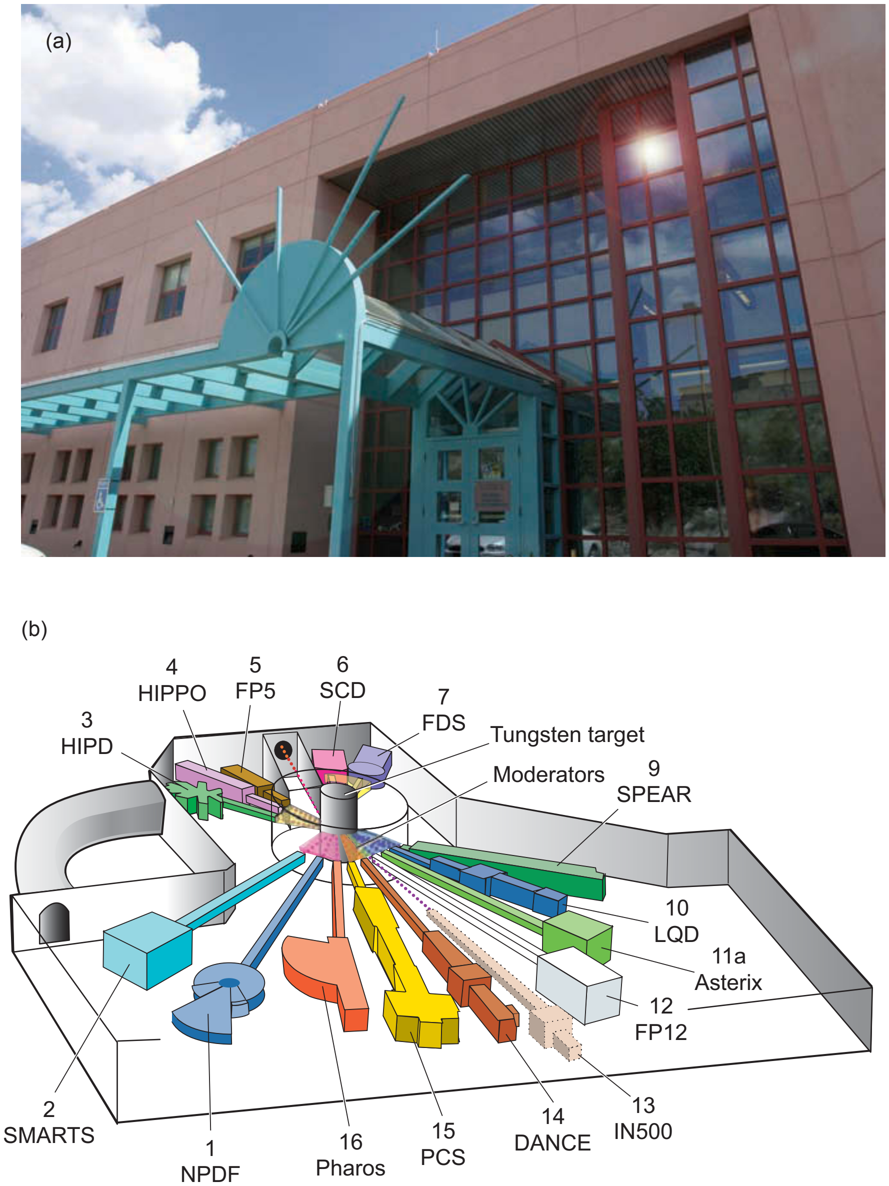

Figure 3. The Lujan Center
Short, intense pulses from the PSR are directed at the Lujan Center's tungsten target, which is coupled to two different neutron moderators for the production of cold, thermal, and epithermal neutrons with energies that span the range from milli–electron volts to kilo–electron volts. The cold moderator, containing liquid hydrogen, is a first-of-its-kind design, featuring neutron coupling to the spallation target and neutron reflector materials; it is optimized for cold-neutron production and produces the most intense peak flux in the world. Neutrons from each moderator source are collimated to form beams for up to seventeen flight paths. These neutron flight paths are instrumented for different purposes, including powder diffraction, reflectometry, small-angle scattering, protein crystallography, inelastic scattering, single-crystal diffraction, and chemical spectroscopy. The entrance to the Lujan Center is shown in (a), and the experimental hall with target, moderators, and instrumented flight paths, in (b).

The LANSCE Facilities

The Lujan Center. This facility (Figure 3) delivers the highest-peak neutron flux in the world for research on materials science and engineering, polymer science, chemistry, earth science and geology, structural biology, and condensed matter physics. High flux at low energies is at a premium in neutron scattering studies because low-energy neutrons, although essential both for penetrating bulk materials and for visualizing the hydrogen content of biological macromolecules, are hard to produce in great quantities and have a much lower scattering probability than x-rays.

Neutron scattering is used to determine where atoms are located in materials and how they move (diffuse or oscillate) collectively as a function of temperature. Elastic neutron scattering provides position information (structure), and inelastic neutron scattering provides information about motion (dynamics). Exactly how the position and motion of atoms affect properties such as strength, compressibility, density, heat capacity, and so forth is one of the grand challenges of materials science, known as the "structure–property relationship." Understanding the connection between material structure at the atomic level or the nanoscale and macroscopic material properties promises both better use of existing materials and the ability to design new materials for specific applications ("designer materials"), a capability that will revolutionize manufacturing and technology in the future. Lujan Center users and researchers are engaged in this pursuit. They have discovered the nanoscale structure of high-temperature superconductors and are exploring its possible relationship to superconductivity, explored the role of strain in stabilizing nanometer-scale magnetic layers used in computer disk read heads and in future magnetic random-access-memory devices, and

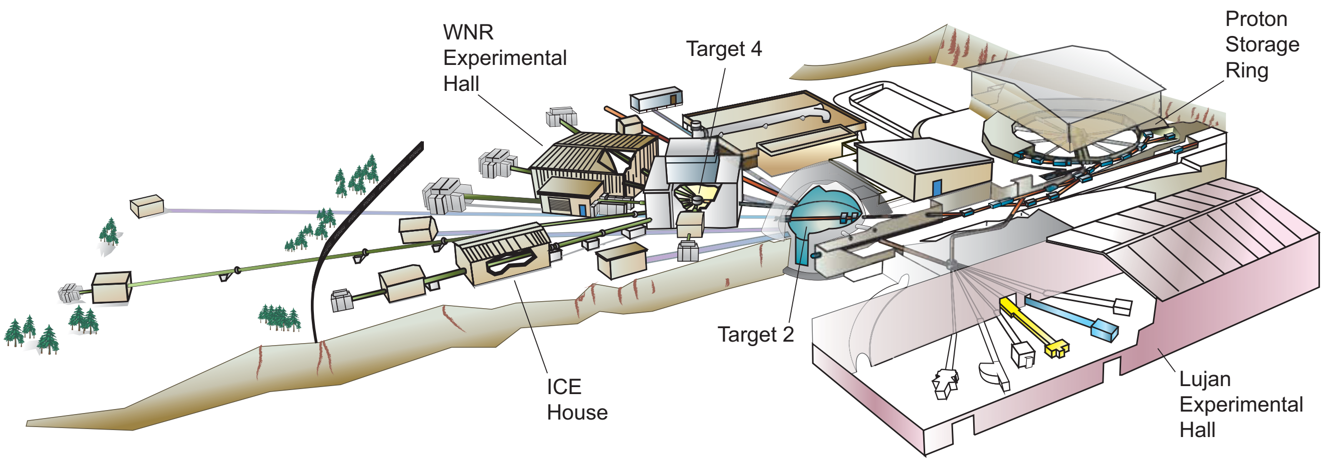

Figure 4. The Layout at WNR
The WNR houses Targets 2 and 4. The latter provides pulses of energetic neutrons to a flexible array of instrumented flight paths.

located specific hydrogen atoms in enzymes and determined the role of those atoms in binding drugs or activating metabolic pathways. (See the articles "Unraveling the True Structure of Exotic Oxides," "Origins of Spin Coupling across Interfaces," and "Finding out How Enzymes Work" on pages 178 and 186, respectively.)

The Lujan Center has seventeen flight paths, twelve of which are instrumented for various neutron-scattering techniques to study materials. In addition, two flight paths are instrumented for neutron nuclear science, one is instrumented for transmission neutron spectroscopy, and two are currently available for future research activities.

The Weapons Neutron Research (WNR) Facility. The WNR houses a flexible array of instrumented flight paths to enable precise nuclear measurements for the weapons program and for fundamental nuclear physics research (Figure 4). This facility is the only sufficiently intense broad-spectrum neutron source for providing the nuclear data necessary for predicting nuclear weapons performance. Developing this science-based predictive capability is crucial to certifying the present and future U.S. nuclear deterrent without testing.

New nuclear data are needed for two major aspects of stockpile stewardship: calculating precisely the nuclear energy production of a weapon as a function of time and benchmarking calculated nuclear performance against previous aboveground or underground test data. The unique research effort at the WNR, coupled to the Laboratory's capabilities for fabricating and handling actinide and radioactive materials, provides an unmatched resource for meeting the requirements of stockpile stewardship. Among these requirements are measuring cross sections on isotopes and nuclear isomers with short half-lives in order to understand radiochemistry results of past nuclear tests (see Figure 5), determining cross sections for neutron-induced reactions on actinide isotopes and weapon materials, and improving our understanding of fission energy production in weapons systems. For example, techniques have recently been demonstrated that enable measuring the fis-

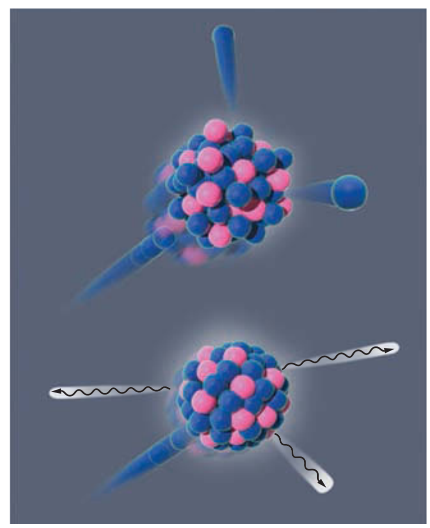

Figure 5. Neutron Reactions for Weapons Diagnostics
(Top) An incoming neutron (blue) knocks out two neutrons from a nucleus. Using the GEANIE detector array at the WNR, this important (*n*,2*n*) reaction on plutonium was measured accurately for the first time. (Bottom) An incoming neutron is captured by a nucleus, which then emits gamma rays. Neutron capture reactions are important for interpreting radiochemical data from past nuclear tests and are now being measured for the first time with the DANCE detector array at the Lujan Center.

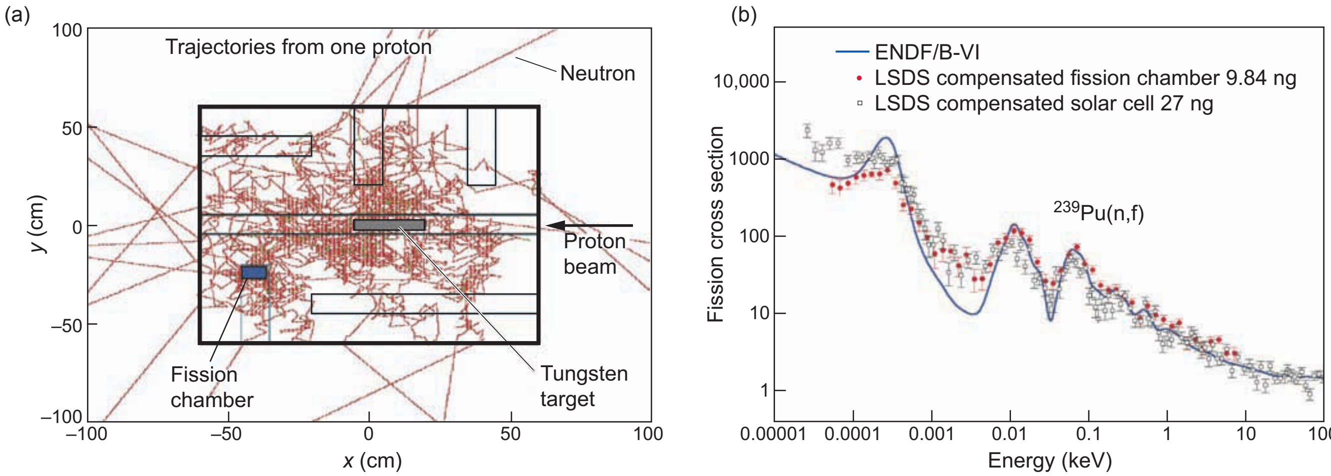

Figure 6. Measuring Fission Cross Sections on Ultrasmall Samples at the WNR
The Lead Slowing-Down Spectrometer (LSDS) at the WNR can measure nuclear cross sections on extremely small, short-lived samples. (a) The LSDS consists of a tungsten spallation target surrounded by 1.2 m^3 of high-purity lead with a fission chamber placed inside the lead cube. Protons striking the tungsten target produce a spectrum of high-energy neutrons that are concentrated in the spectrometer's interior. Neutron trajectories (red) are from one proton and were calculated using Monte Carlo neutron transport codes. The intense neutron flux allows measuring nuclear cross sections with samples as small as 10 ng (the smallest sample ever used in a nuclear physics cross-section measurement). (b) Also shown are recent measurements of the plutonium-239 fission cross section with a 10-ng sample. The LSDS will be used in the near future to measure the fission cross section of uranium-235m, the isomer of uranium-235 with a half-life of 26 minutes.

sion cross section of samples as small as 10 nanograms and investigating fission cross sections of short-lived isotopes and isomers for defense science applications and nuclear astrophysics. (See Figure 6 and the article on nuclear data on page 58).

The Irradiation of Chips and Electronics (ICE) House. As electronic components continue to decrease in size, their vulnerability to single-event upsets (SEUs) by atmospheric neutrons has grown. A few years ago, the WNR began to provide the semiconductor electronics industry with an invaluable capability to irradiate semiconductor components and assemblies and quantify their vulnerability to neutron-induced SEUs. The neutron production spectrum at the WNR reproduces the naturally occurring neutron energy spectrum seen by aircraft electronics in flight, but at one million times the intensity. Recent studies by Honeywell and NASA of a flight control system (Figure 7) showed the benefits of a rollback recovery architecture in mitigating the effects of neutron-induced upsets. The WNR now provides the international standard for testing neutron-induced upsets in electronics, and in the 2004 run cycle, twenty-three industrial companies, universities, and national laboratories used the facility for this purpose (see the articles "The ICE House" on page 96 and "Testing a Flight-Control System for Neutron-

Figure 7. Testing Semiconductor Electronics at the ICE House
At the ICE House, Honeywell and NASA placed a flight control system in the neutron beam (inset) to determine how well the system would recover from upsets induced by atmospheric neutrons.

Figure 8. The pRad Facility
For pRad, 50-ns-wide H^- beam pulses with approximately 10^9 protons per pulse are spaced in time at intervals predetermined by experimental requirements. Transmitted and scattered protons are imaged by an electromagnetic lens system and recorded by cameras. This technique provides multiframe radiographs across a 10-cm field of view that spatially resolves features to an accuracy of approximately 150 μm from samples with an areal density of up to 60 gm/cm^2. In addition, a permanent-magnet magnifier lens is available that provides a factor of 7 magnification for small systems with spatial resolution to roughly 15 μm.

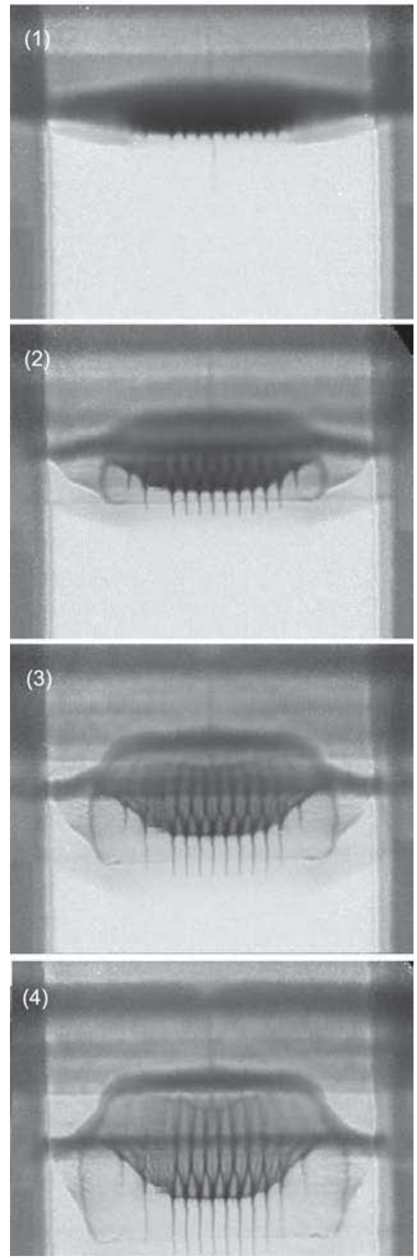

Figure 9. Proton Radiographs of Shock-Driven Ejecta
In this experiment, an explosively driven aluminum flyer plate impacts a solid tin target. The target's surface was machined with a sinusoidal contour. The resulting nonlinear growth resulting from Richtmyer-Meshkov instabilities is clearly visible in the pRad images from (1) to (4). Such experiments are used to benchmark analytic theories and hydrodynamic simulation tools used for nuclear weapon certification.

Induced Disturbances" on page 104).

The Proton Radiography (pRad) Facility. The pRad facility provides a unique capability for the study of dynamic processes using 800-MeV protons and a magnetic-lens imaging system (Figure 8). Because protons interact with materials through both the strong nuclear force and the electromagnetic force, transmission measurements allow simultaneous imaging and determination of material properties.

Los Alamos National Laboratory, in collaboration with Lawrence Livermore National Laboratory and other national laboratories, developed and successfully applied pRad to meet the mission requirements of stockpile stewardship. Proton radiography is a powerful tool for elucidating basic principles of how nuclear weapons work. It is arguably the most valuable single tool available to interrogate the hydrodynamic phase of a weapon. It is necessary to develop and validate quantitative models of material properties and hydrodynamics for this phase that can be implemented in new computer simulation codes from the Advanced Simulation and Computing (ASC) Program. These models must capture critical hydrodynamic behaviors with high accuracy, and achieving that goal sets the hydrodynamic-data requirements. Although many diagnostic tools have been developed to assess the hydrodynamic behavior of materials, most rely on surface measurements and are unable to interrogate the critical state variables and stress-strain response in the interior of the materials. Modeling depends on accurately capturing the time evolution of the hydrodynamics on a microsecond time scale (Figure 9). Proton radiography, with its ability to penetrate and accurately image the interior of highly compressed materi-

(a)

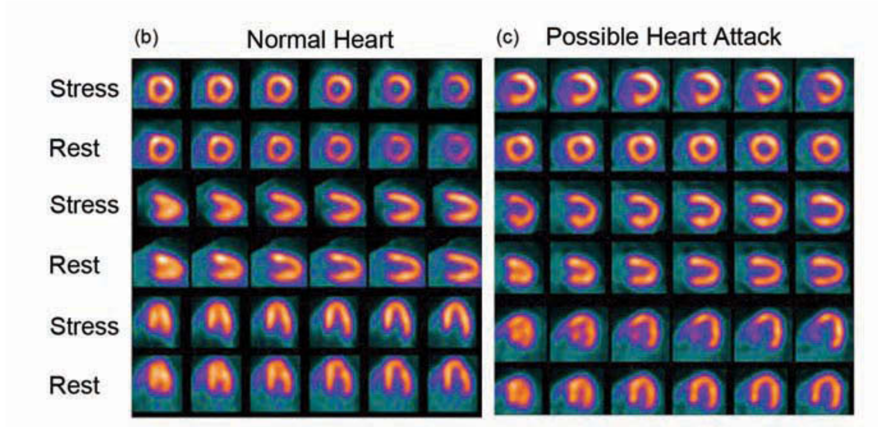

Figure 10. Producing Radioisotopes for Cardiac Scans
The radioisotope strontium-82 produced at the new Isotope Production Facility (IPF) at LANSCE is the source of rubidium-82, an ideal tracer for scanning the heart. (a) A technician manipulates irradiated targets in the hot cell facility at the IPF. (b) and (c) Shown here are heart scans obtained by positron emission tomography. Alternating rows show images of the heart after stress and after a period of rest. Each pair of stress and rest images shows a different cross section of the heart.

als, as well as its highly flexible and precisely recordable pulse format, is uniquely suited to providing these necessary data for weapon certification codes and models.

The Isotope Production Facility (IPF). The new IPF continues a 30-year Los Alamos tradition of supplying advanced accelerator-produced radioisotopes for both research and nuclear medicine. Los Alamos and Brookhaven National Laboratories have the only such facilities in the United States. A new proton transport line delivers 100-MeV protons from the existing LANSCE accelerator to the IPF target station. That station is designed specifically for the efficient production of radioisotopes. Targets of different materials are irradiated in a stacked configuration to allow varying the incident neutron energy and thereby optimize production of the desired radioisotopes. Some of those are distributed through pharmaceutical companies for use in cardiac scans and other medical diagnoses as well as medical treatment and research (Figure 10). Others are used for nuclear data experiments of importance to the weapons program, threat reduction studies related to the dispersal of radioactive materials, and basic nuclear physics research. The IPF was designed to operate with minimal impact on scheduled beam delivery to other experimental areas at LANSCE.

The Ultracold Neutron (UCN) Source. The UCN source is being commissioned at LANSCE. Ultracold neutrons have millikelvin temperatures and move at speeds of less than 8 meters per second. Because their wave functions are totally reflected from certain materials, they can be stored in a specially designed container, far from background radiation. Thus UCNs provide an ideal system for high-precision tests of the weak interaction as described in the Standard Model of particle physics. At a planned current of 4 microamperes, preliminary measurements indicate that the UCN source at LANSCE will be the most intense one of its kind worldwide. Once the LANSCE source becomes operational at full power, a series of fundamental physics measurements will be conducted, the first of which is a measurement of the β-decay asymmetry resulting from the decay of polarized UCNs. This experiment could detect physics beyond the Standard Model, thereby changing our ideas of how the fundamental forces in the universe work. A future goal for the UCN facility is to operate as a fourth national user facility at LANSCE for research that delves into the basic structure of matter.

The source uses solid deuterium at 5 kelvins to cool, or moderate, neutrons from a tungsten spallation target coupled to a set of graphite-beryllium and cold polyethylene moderators. The ultracold neutrons pass through guide tubes to nearby experiments.

National Security and Defense Science: The Stockpile Stewardship Program

The nuclear test moratorium era has led to fundamental changes in the way the weapons program certifies whether the U.S. stockpile will achieve its designed performance characteristics. When nuclear tests were conducted, the pedigree of a particular nuclear explosive package was evaluated experimentally with underground tests. The overall confidence in the continued performance of devices in the

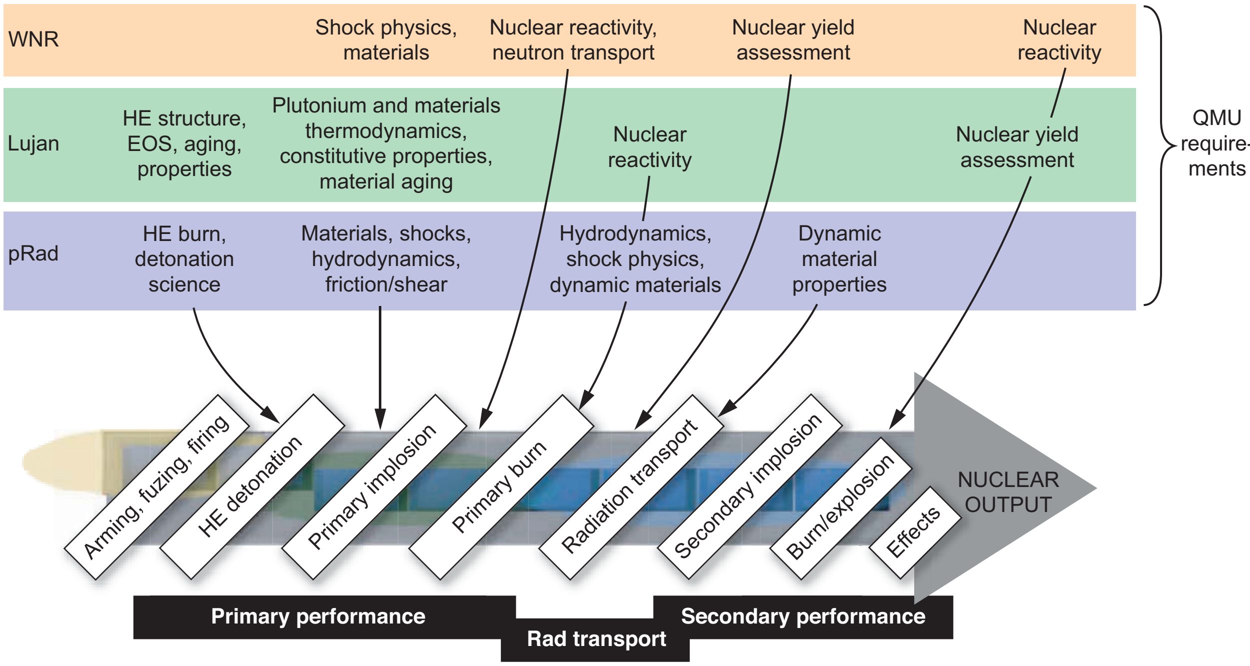

Figure 11. Supporting Science-Based Predictive Capability
As shown in this diagram, LANSCE capabilities uniquely address science-based prediction, necessary for present and future weapons certification.

stockpile relied heavily on the expert judgment of designers with significant underground-test experience. In the absence of testing, a new certification methodology is required, namely, science-based prediction of weapon performance. Quantification of margins and uncertainties (QMU) provides this construct (Figure 11).

QMU is based on the capability to quantitatively predict the performance of a nuclear explosive package, including the performance margin and associated uncertainties, that is, how close the system is to the point at which it would begin to fail to perform as specified. This capability is firmly rooted in our ability to accurately model weapon performance across a broad range of physical conditions. LANSCE facilities are presently used to meet this scientific grand challenge with research that explores many aspects of weapons science and behavior.

All three National Nuclear Security Agency (NNSA) laboratories, as well as the Atomic Weapons Establishment in the United Kingdom, utilize LANSCE's unique facilities to address issues related to weapons assessment and certification. In the past 5 years, LANSCE research has produced high-explosive data underpinning the certification of the B61 nuclear warhead to meet specific performance requirements, nuclear data critical to revising the baseline performance of the W88 primary, and materials data validating the reuse of components in the W76 Lifetime Extension Program. Specific research areas in support of weapons certification include the following:

- Investigating the behavior of high-explosive (HE) materials, including the equation of state and constitutive properties affected by aging
- Assessing the effect of aging on stockpile materials and associated performance
- Resolving uncertainties in insensitive-high-explosive burn and dynamic material properties under different environmental conditions
- Employing scaled experiments to quantify the hydrodynamics phase of a weapon and to test performance models
- Determining the constitutive properties of weapons metals, such as plutonium, at high temperature and pressure
- Quantifying the effects of manufacturing changes, such as changes in fabrication processes, on performance
- Providing high-accuracy nuclear cross sections for actinides and radiochemical isotope chains (including short-lived isotopes) to interpret archival underground nuclear tests and validate weapons performance predictions

In the future, our science-based predictive capabilities must continue to improve in order to ensure the

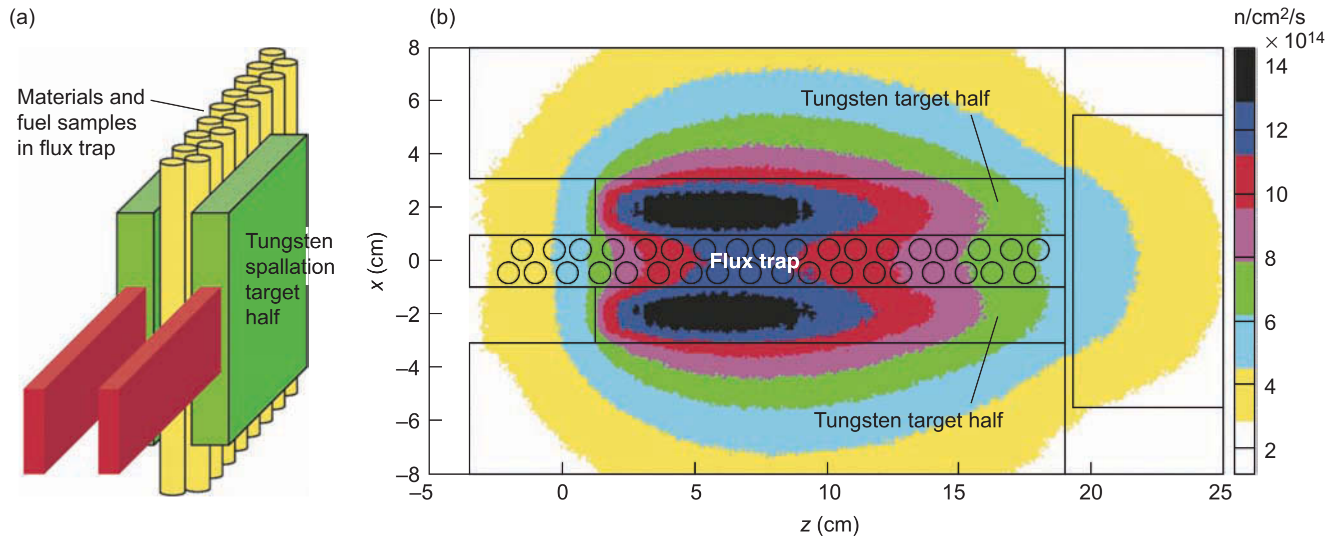

Figure 12. Testing Nuclear Fuels at the MTS
(a) At the MTS, nuclear fuel rods designed for a closed fuel cycle will be placed between a split tungsten target and irradiated by a fast neutron flux. (b) The plot shows the neutron flux intensity that the proton beam from the LANSCE linac will produce when it strikes the tungsten target. The fast-neutron flux in the flux trap region between the tungsten halves will be nearly 10^{15} neutrons/cm^2/s, equal to that of a typical fast reactor.

accuracy of our stockpile assessments as weapons age and components are refurbished or replaced. These capabilities will remain crucial to certification if and when a reliable replacement warhead is developed and fielded. LANSCE is poised to meet these future challenges through capability enhancements and continued engagement with the best of the scientific community.

National Energy Security

Over the past fifty years, the development of commercial nuclear power has successfully relied on thermal reactors—mostly water-cooled reactors, which run at relatively low temperatures with thermal, or low-energy, neutrons driving the controlled-fission-chain reaction. However, inefficient use of nuclear fuel, risks of nuclear proliferation, and the problem of safely storing large quantities of nuclear waste in geologic repositories for thousands of years have revitalized interest in adding fast-neutron fission systems to the nuclear fuel cycle. Fast, or high-energy, neutrons are much more efficient than thermal neutrons at transmuting long-lived actinides with half-lives of several hundred thousand years (plutonium, neptunium, americium, and curium), thereby eliminating them from nuclear waste and drastically reducing the long-term decay heat, radiotoxicity, and proliferation risks that make nuclear waste such a difficult problem.

To support the National Energy Policy, the Department of Energy (DOE) has initiated several programs focused on fast-spectrum reactor and fuel cycle concepts that can reduce the spent-fuel demands on geologic repositories by improving the utilization of nuclear fuels and the transmutation of long-lived transuranic waste products. These advanced concepts employ nontraditional fuels, structural materials, and coolants for which there is currently insufficient operating knowledge. Assessment of these concepts requires testing where fuels and materials are irradiated under actual or prototypical fast-reactor flux conditions and operating environments. Currently, there are no fast-reactor or fast-flux test facilities in the United States that meet the required irradiation environment.

Because LANSCE can reestablish full-power (1 milliampere) proton acceleration, it is poised to provide a new U.S. capability for the production of fast neutrons. The Materials Test Station (MTS) will achieve neutron intensity levels equivalent to a 100-megawatt fast-flux reactor. The neutron intensity will be sufficient to research and improve the next generation of materials and fuels necessary to deploy advanced fission systems for U.S. energy security (see Figure 12). The MTS irradiation capability, in concert with its post-irradiation examination capabilities, will provide necessary data for the validation of materials simulation models enhancing science-based prediction of materials behavior. This capability will be an integral component of the fast-reactor development program, serving as the nation's premier source of high-intensity fast neutrons. In addition, the MTS at LANSCE will provide a world-class capability to help develop the advanced materials needed for fusion energy systems.

Role of LANSCE in Materials Science and Bioscience

Neutron scattering research began in the late 1940s as reactors that produce considerable neutron flux were built for nuclear energy research. Over the past few decades, with the advent of more-intense neutron sources and energy-discriminating time-of-flight techniques, neutron scattering has emerged as a major exploratory tool for understanding condensed matter. Neutron scattering data were seminal in understanding the structure and dynamics of the first high-temperature superconductors and have played a role since then in the discovery of many unexpected and counterintuitive phenomena in electronic, magnetic, optical, and structural materials, as well as in biomaterials and nanomaterials.

The impact of neutron scattering is evident across the entire field of materials science. Recent examples of that impact at Los Alamos include understanding the anomalous thermal expansion of plutonium, elucidating the physics of new superconductors and magnetic materials, the discovery of water inclusions in DNA structure, and the identification of material failure modes in high-consequence accidents. Other examples are shown in Figures 13–15: predicting the lifetime of weapons parts, discovering new materials under pressure, and using the protein crystallography station to track the motive power of single hydrogen atoms during enzymatic reactions. The growing power of neutron sources and increasing sophistication of associated instrumentation ensure an expanding role for neutrons in materials research, including the performance and aging of weapons materials and the development of new materials needed for threat reduction.

The Lujan Center is presently the premier U.S. spallation neutron source and produces the highest-peak flux for cold neutrons in the world. Cold (or long wave-length) neutrons are ideal for studying soft materials, biomaterials, and nanomaterials, which are predicted to be at the forefront of materials science for the next several decades. Biomaterials are among the coarsest and softest of materials classes while having the most complex properties. Both structure on larger scales and dynamics at lower energy become important in these materials. Neutron scattering studies of biomaterials with cold-neutron techniques are therefore essential to uncovering the scientific principles by which biomaterials exhibit

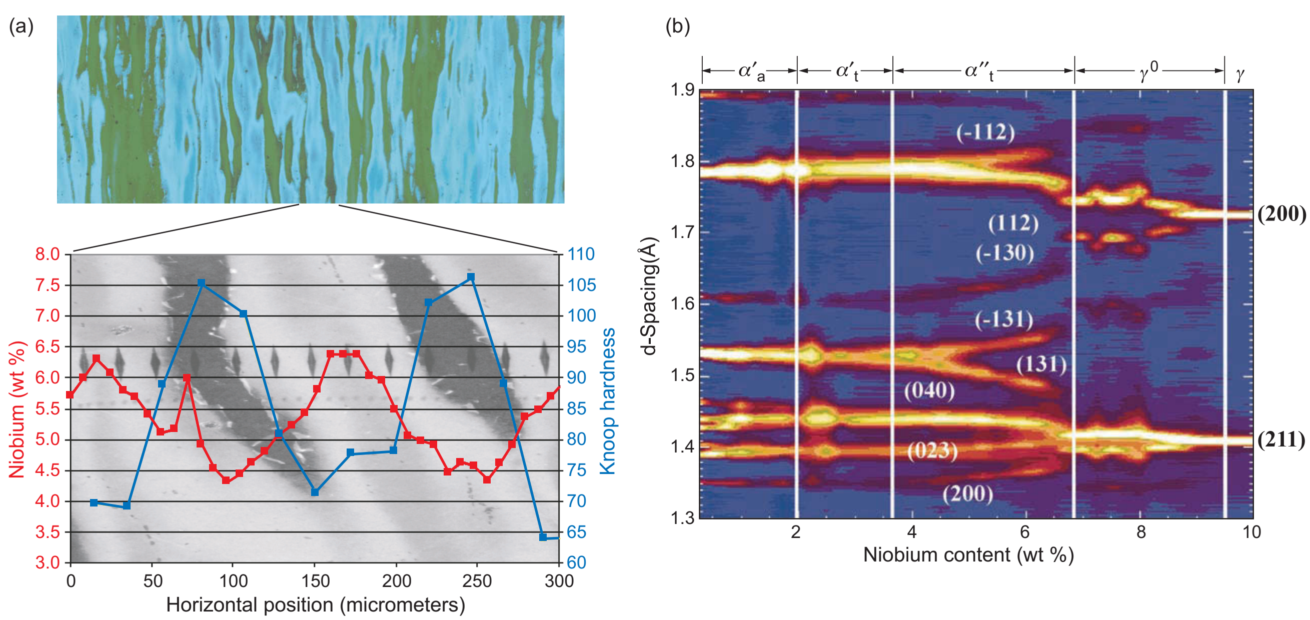

Figure 13. Predicting the Lifetimes of Uranium-Niobium Nuclear-Weapon Parts
(a) Rolled uranium-niobium parts exhibit a metastable striated structure (top) with large variations in niobium content and hardness (bottom). (b) Diffraction measurements at LANSCE identify the crystal phases present in homogeneous uranium-niobium alloy as the niobium content increases. Other diffraction measurements reveal that under stress, the crystal structure of uranium-niobium alloy with 6 weight-percent niobium deforms mainly by reorienting its crystalline "twins." All these data can be used in computer models to accurately predict lifetimes and weapon performance.

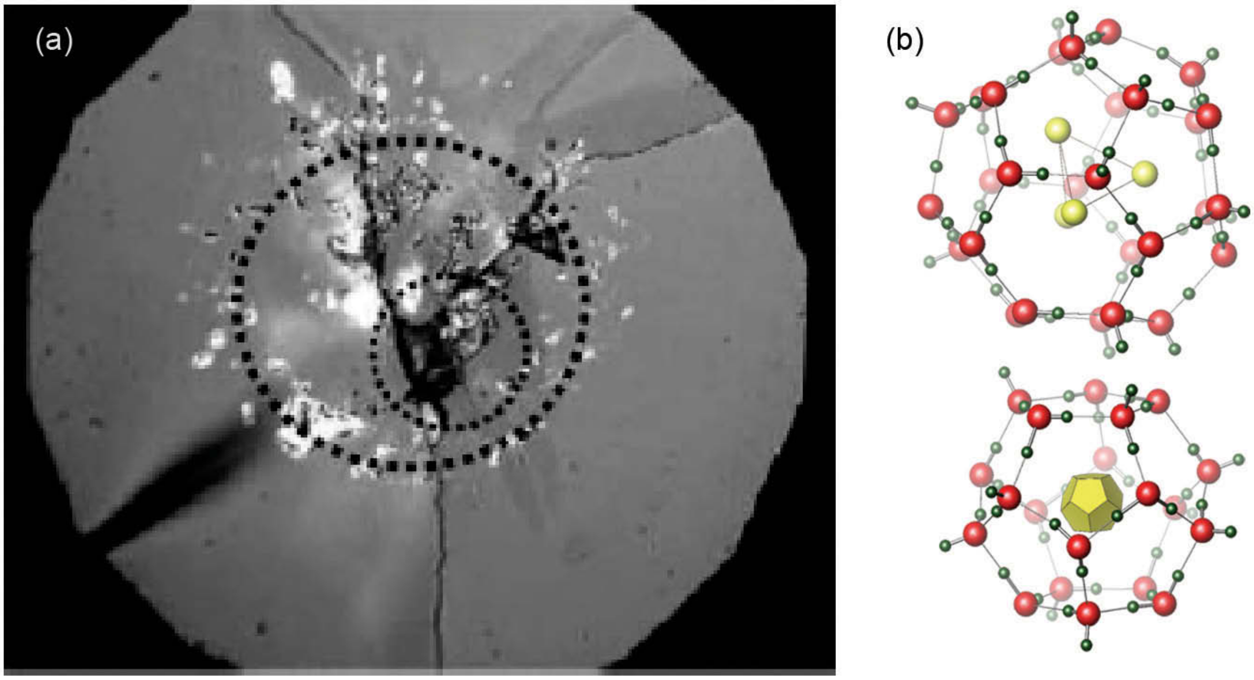

Figure 14. New Materials Discovered at High Pressures
(a) This indentation micrograph shows a new carbon phase whose density, hardness, and bulk modulus are at least as high as those of diamond. The new phase forms when carbon nanotubes are compressed to 75 GPa. (b) A new hydrogen clathrate formed from ordinary water traps hydrogen molecules (yellow) in large (top) and small (bottom) molecular cages at concentrations rivaling those of the best hydrogen-storage materials. The oxygen and hydrogen atoms in the cages' water molecules are shown in red and green, respectively.

(a) (b)

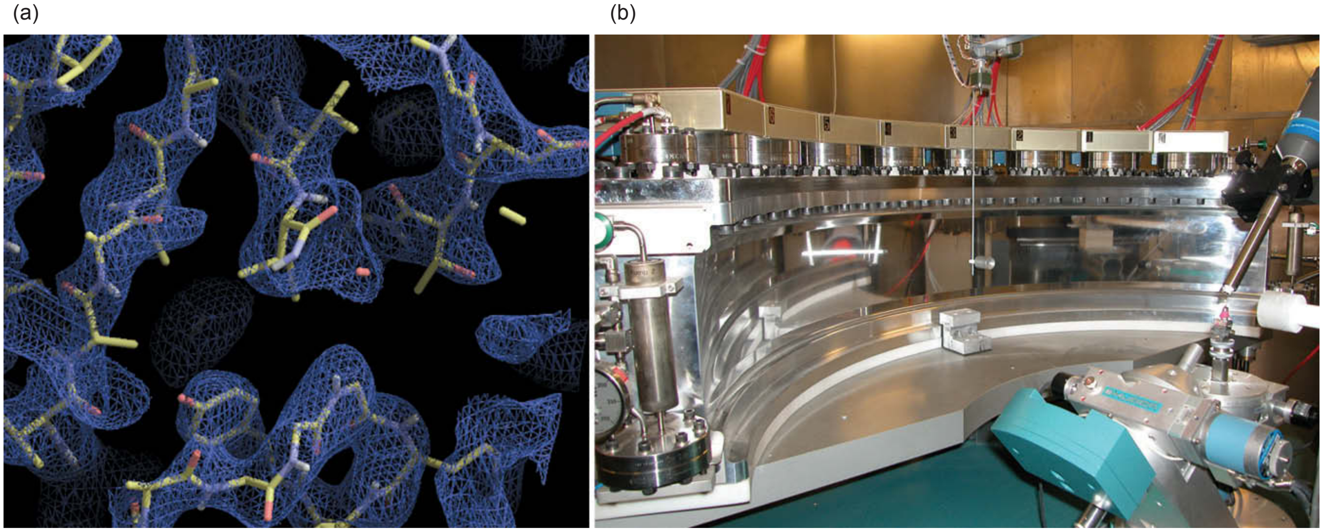

Figure 15. Improving Drug Design
(a) The antitumor drug methotrexate inhibits DNA from being produced by tight binding to a pocket in the cleft of the protein DHFR. The hydrogen density distribution of DHFR determined by neutron scattering is shown by the netlike structure. (b) Using the new protein crystallography station, scientists have identified the hydrogen bonds in DHFR responsible for binding methotrexate. That information will help them improve drug design.

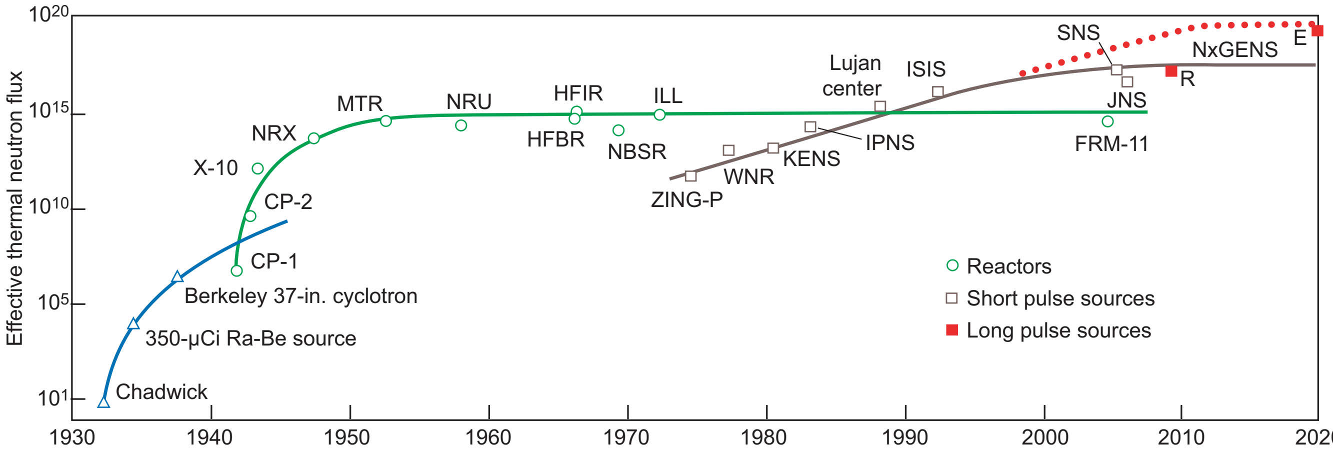

Figure 16. The Long-Pulse Spallation Source

Spallation sources that produce long pulses at low repetition rates are likely to achieve very-high-power, high-brightness cold neutrons for studying the properties of soft matter. Plotted on the graph are the effective fluxes of neutron sources worldwide and the dates the sources were commissioned. Reactor sources have increased in effective flux by only a factor of 4 since the first reactor for neutron scattering was built at Chalk River in the late 1950s. Further progress in creating higher fluxes relies on long-pulse sources. The proposed NxGENS long-pulse spallation source planned at LANSCE would fully demonstrate long-pulse technology.

self-assembly, self-limited growth, healing, and adaptive emergent properties. Nanomaterials share many characteristics with soft materials; the essential structural features occur on supramolecular scales. The preferred synthesis path for soft nanomaterials is bottom-up self-assembly, whereby specific short-range interactions are engineered into complex precursor macromolecules that induce long-range order by cooperative physical interactions. Again, neutron scattering with cold-neutron techniques is essential to exploring nanostructure.

The evolution of materials science holds a very bright future for LANSCE as plans develop to capitalize on the high-peak flux of cold neutrons and low pulse-repetition rate. Operating at a pulse repetition rate of 20 hertz, the Lujan Center is unique compared with other existing or planned facilities. For example, the Spallation Neutron Source (SNS) to be built in Oak Ridge, Tennessee, will operate at 60 hertz, and ISIS, the pulsed neutron and muon source in the United Kingdom, presently operates at 50 hertz. Low repetition rate allows for the use of all the cold neutrons in a pulse and thus leads to efficiency. By fully using the neutron scattering instrumentation, the Lujan Center can take full advantage of its high-peak flux for cold-neutron-scattering research. This strategy will ensure that the Lujan Center maintains its preeminent role in cold-neutron scattering in partnership with the SNS and other future megawatt-class neutron scattering centers.

It is clear, however, that the future frontiers of structural biology and dynamic self-organization of materials will require neutron sources with at least ten times the cold-neutron flux presently planned or available. These so-called Generation III neutron sources are likely to utilize a long-pulse spallation source (LPSS)—see Figure 16. Future LANSCE capabilities, associated with the Materials Test Station for nuclear energy research, will allow the United States to prototype a Generation III source with a single flight path at relatively modest cost. This prototype, called NxGENS, will be a cost-effective approach to complement the SNS capability. If fully developed, NxGENS will substantially exceed SNS performance. The NxGENS prototype will assure U.S. leadership in Generation III neutron sources by offering unprecedented research opportunities in cold-neutron scattering.

As envisaged, the NxGENS prototype will operate with an 800-MeV beam at a power of 660 kilowatts and a repetition rate of 20 hertz. It will perform in short-wavelength applications (for example, diffraction and strain analysis) at about the same level as the current Lujan Center, and in cold-neutron-scattering applications, at about the same power level as the SNS. The cold-neutron applications include small-angle neutron scattering, reflectometry, protein crystallography, neutron spin-echo spectroscopy, and low- or variable-resolution time-of-flight spectroscopy. The NxGENS prototype could be further enhanced to accommodate multiple flight paths operating at 2.5 megawatts, thus promising an improvement in cold-neutron production greater than one order of magnitude over planned high-power

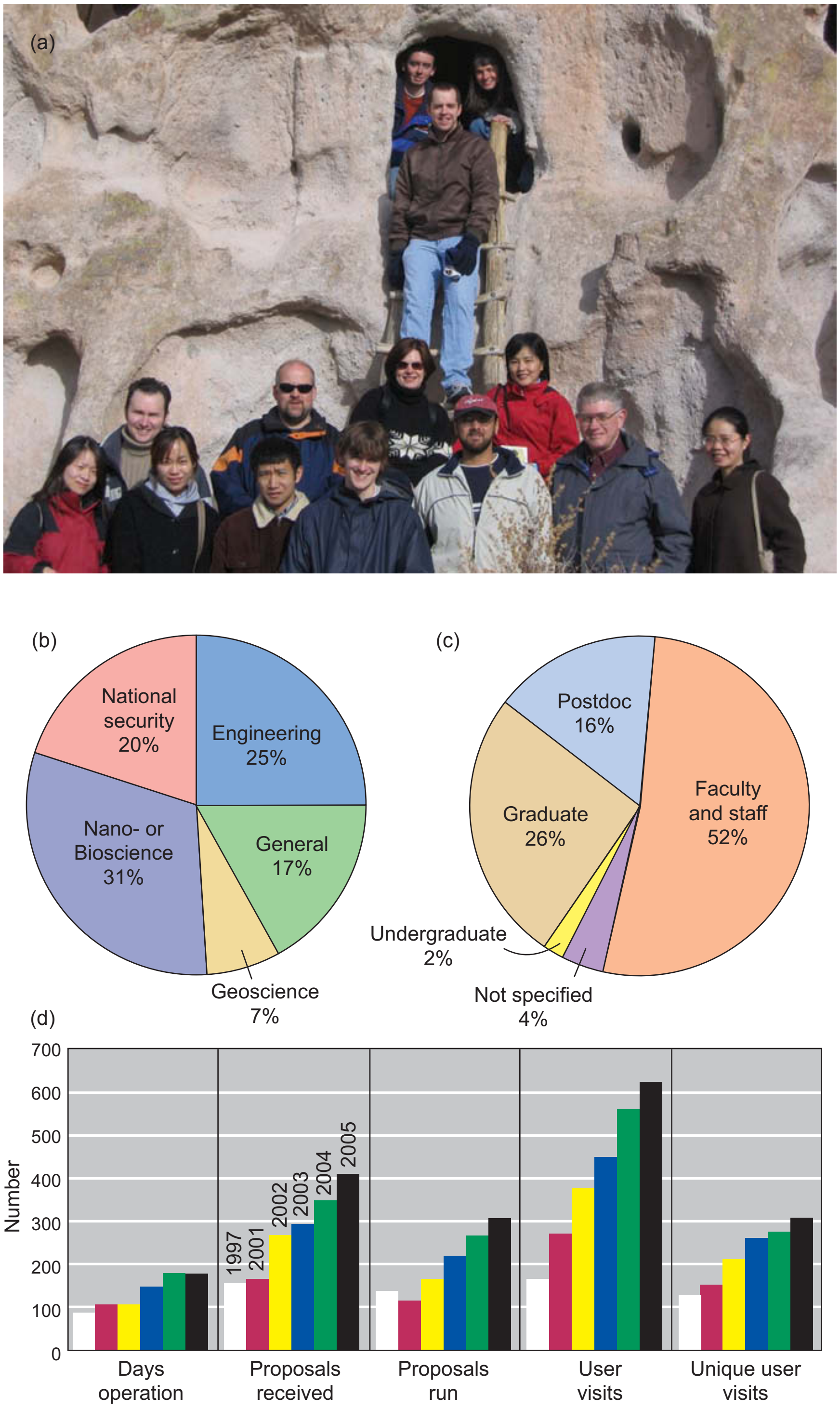

Figure 17. The User Program at the Lujan Center
(a) Some of the students attending the 2004 LANSCE Neutron Scattering Winter School are pictured here with Jim Rhyne and Thomas Proffen of LANSCE. The pie chart in (b) shows the different areas of research in which Lujan Center users are involved, and the one in (c) shows the users' demographics. The bar chart in (d) shows the steady growth of the Lujan Center User Program between 2001 and 2005.

short-pulse sources. The NxGENS source would overcome intrinsic limitations of present and planned short-pulse sources and will be well suited to 21st century materials research for national security.

Role of LANSCE in Los Alamos Scientific Infrastructure

The success of an institution depends on the facilities, people, and purpose to which it is dedicated. For 30 years, LANSCE has created a unique scientific environment, attracting scientists from around the world to work together on high-stake issues related to global security, as well as on exciting challenges at the frontiers of knowledge. Today's national and global-security imperatives lend extra emphasis and meaning to research that already has high intellectual merit.

The last several years have seen a steady stream of new technologies come on line at the LANSCE user facilities: four new world-class instruments for high-precision nuclear physics measurements at the WNR and Lujan Center, high-resolution imaging devices for pRad, the first facility for ultracold-neutron research, and seven new instruments for materials science and bioscience on the floor at the Lujan Center. The Lujan Center, in combination with the new Center for Integrated Nanotechnology and the National High Magnetic Field Laboratory, makes Los Alamos a premier destination for materials scientists interested in materials structure and synthesis, nanoscience, structural biology, and high magnetic fields and pressure. The new LANSCE instruments and Los Alamos facilities were supported through investments by the NNSA Office of Defense Programs, the Office of Basic Energy Sciences in the Office of Science at DOE, the National Science Foundation, and the

Laboratory-Directed Research and Development Program at Los Alamos.

Not surprisingly, this burst of creativity and investment was accompanied by a steady and dramatic increase in the number of experiments, users, and individual user visits, as well as in the level of user satisfaction every year since 2001. As illustrated in Figure 17, during the 2004 run cycle, for example, over 500 user visits were logged in at the WNR and another 500 at the Lujan Center, and that rate of growth continues unabated during the 2005 run cycle. The demographics are also impressive. At the Lujan Center, almost half the users are students and postdoctoral researchers conducting publishable research of a more fundamental nature, and nearly two-thirds are early-career scientists. A contributing factor to these healthy demographics is the LANSCE Neutron Scattering Winter School, a topical school started in 2004, which hosts 30 students for nine days of hands-on experimentation, as well as instruction by a dozen world-class lecturers. Thus, LANSCE continues to be a magnet facility for scientific talent. The Laboratory can point to well over 1200 people who have joined the Laboratory permanently after having been at LANSCE, and many of those have contributed significantly to the Laboratory's core mission.

Major Benefits of LANSCE Enhancements

Improving proton radiographic imaging at 800 MeV and exploring higher-energy, more-intense beams to fully resolve dense, full-scale systems for hydrotesting

Enabling nuclear-cross-section measurements on short-lived isotopes for higher-fidelity weapons nuclear data and data relevant to nuclear astrophysics

Enhancing burst production of neutrons for testing electronic components of weapons

Improving the irradiation capability for materials testing with the MTS

Upgrading the Lujan Center to achieve full scientific utilization with full-flight-path instrumentation serving 750 users per year

Demonstrating the NxGENS neutron scattering source and flight path using the long-pulse format that will attain unprecedented cold-neutron scattering performance

Developing the best-in-the-world ultracold-neutron source for fundamental nuclear-physics research

LANSCE Futures

Future national missions will require enhanced LANSCE capabilities to support five principal research areas: (1) pRad to meet the mission-critical requirements of the Stockpile Stewardship Program for the next decade; (2) weapons nuclear science to meet Stockpile Stewardship Program and Homeland Security mission requirements and to provide an international standard for qualifying semiconductor components and systems for performance during single-event upsets; (3) civilian nuclear science to enable operation of the Materials Test Station, meeting the needs of nuclear reactor research for future energy security; (4) materials science and bioscience to enhance neutron scattering performance at the Lujan Center for understanding the performance and aging of weapons materials, to support development of the broad spectrum of new materials needed for stockpile stewardship and threat reduction, and to develop NxGENS, a prototype Generation III long-pulse spallation neutron source, where future materials science and bioscience discoveries would be made; and (5) fundamental nuclear physics to enable the reliable production of cold and ultracold neutrons at unprecedented intensities and densities, which make it possible to conduct revolutionary research and thereby keep the United States at the forefront of fundamental nuclear physics.

Proposed LANSCE performance enhancements are focused to address specific mission requirements for multiple sponsors over the next 20 years. Our strategy is to start with enhancements to LANSCE facilities that fully exploit existing capabilities using 800-MeV protons and then to proceed with upgrades to accelerator energy and power that enable new and significant upgrades to facility performance. The enhancements will result in major benefits, some of which are summarized in the box above.

The LANSCE facility serves as a cornerstone in our national security and defense missions through its scientific excellence in research critical to those missions. Future LANSCE enhancements will ensure that this important role in national defense is maintained over the next two decades. ■